Agglomeration Externalities in Germany

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Abstract

Several recent econometric investigations found externalities related to the density of economic activity to account for one fifth to one half of total regional variations in average labor productivity in the U.S. and big European countries, including Germany. The present paper shows for German NUTS 3 regions, first, that this result is not robust against a more extensive control for private returns that may be correlated with economic density. The paper presents, second, evidence of various types of agglomeration economies, including labor-market pooling, human-capital externalities, localized R&D spillovers, gains from the variety of intermediate goods, to affect regional productivity significantly. Although the productivity effects of these externalities within regions cannot be identified because they are observationally equivalent to individual returns, they can be identified by exploiting the spatial dimension of the data.

JEL: C21, R12

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Contents

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I. Introduction

According to a number of recent econometric investigations, agglomeration externalities foster labor productivity, rents, and wages in regions with high economic density to a significant extent. Evidence from aggregate regional data suggests that the density externalities account for between one fifth to one half of total regional variations in average labor productivity in the U.S. and big European countries (Ciccone and Hall 1996; Ciccone 2002; Baptista 2003). The elasticity of average labor productivity with respect to employment density (as a proxy for the externalities) was estimated to be between four and seven per cent. Dekle and Eaton (1999) found similar density effects on labor productivity and rents in Japan. Empirical evidence from various microeconometric investigations suggests that urban wage premia are significant as well (e.g., Wheaton and Lewis 2002; Glaeser and Maré 2001; Möller and Haas 2003). The elasticities of individual wages with respect to economic density were estimated to be somewhat lower than the elasticities of average labor productivity, however.[1] In general, the results can be taken as evidence for urbanization economies to be significant, although the density of economic activity is not an unequivocal, and not the only indicator of urbanization economies.

The present paper addresses some of the apparent conceptual weaknesses of the macroeconometric investigations. Extending the theoretical framework proposed by Ciccone and Hall (1996) in several respects, and testing the extensions using a data set for West German NUTS 3 regions (Landkreise), the paper arrives at fundamentally different results. The extensions allow, first, for controlling more extensively for private returns which may be correlated with urbanization economies, or economic density. The paper shows that the estimated productivity effects of economic density disappear almost completely once private returns are controlled more extensively. And second, the extensions allow for gaining a few insights into the empirical relevance of externalities other than those related to economic density. Since the productivity effects of these externalities, which may be labeled localization economies for simplicity, cannot be identified at the aggregate level within regions because they are observationally equivalent to private returns, the present paper focuses on the effects of externalities spilling over from neighboring regions. The paper finds evidence of externalities related to the supply of labor and of commercial sites, to human capital intensity, and to firm size to affect productivity significantly, indeed.

The paper is organized as follows: section II introduces the basic theoretical approach developed in Ciccone and Hall (1996) and discusses the extensions. Section III addresses a number of econometric issues. Section IV presents the empirical results for the full extended model,

1 See Moretti (2004) and Rosenthal and Strange (2004) for recent excellent reviews of the empirical evidence.

while section V summarizes the results of tests of individual extensions. Section VI, finally, summarizes and outlines prospects for future research.

II. Theoretical framework

1. The Ciccone/Hall approach

The point of departure of the model developed in Ciccone and Hall (1996), and adopted in Ciccone (2002) and Baptista (2003), is a production function for a representative square kilometer (or acre) of land i within a region (r).[2] Local output on that square kilometer, Y_i, is assumed a function of local private-sector inputs of labor, L_i, and physical capital, K_i, and a region-wide agglomeration externality which is assumed to be proportional to output density in the region as a whole, Y_r/A_r:

$$Y_i = Q_r \left(E_i L_i\right)^{\alpha} K_i^{\beta} \left(Y_r / A_r\right)^{\lambda} . \tag{1}$$

E_i denotes a measure of labor efficiency, α and β the elasticities of output with respect to labor and capital,[3] Q_r an index of total factor productivity (TFP) across all square kilometers within region r, Y_r and A_r total regional output and area (in km²) in r, and λ the output elasticity of economic density. $\lambda>0$ indicates positive, $\lambda<0$ negative output effects of density.

To accommodate data availability, (1) is aggregated across all square kilometers within region r, assuming labor and physical capital to be distributed equally across space within the region. The aggregate production function for region r can be written as

$$Y_r \left[= A_r Y_i\right] = Q_r \left(E_r L_r\right)^{\alpha} K_r^{\beta} A_r^{\gamma} \left(Y_r / A_r\right)^{\lambda} , \tag{2}$$

where E_r is an index of labor efficiency, L_r ($L_r=A_rL_i$) total employment, and K_r ($K_r=A_rK_i$) total physical capital in region r. γ ($\gamma=1-\alpha-\beta$) denotes the output elasticity of land inputs.

Lacking reliable statistics on the stock of physical capital at the regional level, the individual profit maximizing capital stock, $K_r=Y_r\beta/r$, is substituted into (2). The rental rate of capital (r) is assumed to be the same across regions. Moreover, labor efficiency (E_r) is assumed to be

2 Ciccone and Hall (1996) showed that their empirical model is consistent with several theoretical models, including a new economic geography model with non-tradable differentiated intermediates, and a model with Cobb-Douglas technology and increasing returns from agglomeration externalities. The present paper focuses on the latter. The representation of the model in the present paper differs somewhat from that in Ciccone and Hall (1996) and Ciccone (2002) to make explicitly clear that land is an input into private-sector production, and that output is assumed to be subject to constant returns to scale in labor, capital and land.

3 In what follows, the term "output elasticity of X" will be used as a shorthand for elasticity of output with respect to input X.

proportional to the average years of education of the regional workforce (S_r). After some re-arrangements, a reduced form

$$Y_r = \left(\frac{\beta}{r}\right)^{\beta\theta} Q_r^{\ \theta} S_r^{\eta\alpha\theta} L_r^{\ \alpha\theta} A_r^{\ 1-\alpha\theta}, \tag{3}$$

θ=1/(1-β-λ),

can be derived, where η denotes the elasticity of the labor efficiency with respect to schooling. In the literature, (3) was estimated in several versions: In Ciccone and Hall (1996), where regions were chosen to be U.S. counties, (3) was aggregated to the level of states because county-level data on value added were found poorly reliable. The final empirical model was

$$\frac{Y_s}{L_s} = \frac{\sum_{r\in R_s} Y_r}{L_s} = \left(Q\beta^{\beta} r^{-\beta}\right)^{\theta} \frac{\sum_{r\in R_s} S_r^{\eta\alpha\theta} L_r^{\ \alpha\theta} A_r^{\ 1-\alpha\theta}}{L_s}, \tag{4}$$

which allowed for retaining the information on differences in density between the counties within each state. R_s denotes the set of counties in state s. TFP, Q, was assumed to be the same in all states, except for some random variation.

In Ciccone (2002), where regions were chosen to be European NUTS 3 regions, (3) was extended by interregional spillovers of density-related agglomeration externalities, and by a set of NUTS 2 or NUTS 1 dummies to control for differences between regions in TFP (*country/regional dummies*). The final empirical model was

$$\frac{Y_r}{L_r} = \left(Q\beta^{\beta} r^{-\beta}\right)^{\theta} S_r^{\eta\alpha\theta} \left(\frac{L_r}{A_r}\right)^{\alpha\theta-1} \left(\frac{Y_{Nr}}{A_{Nr}}\right)^{\alpha\theta\mu} (country\,/\,regional\ dummies)^{\xi}, \tag{5}$$

where Y_{Nr} and A_{Nr} denote output and total area in region r's neighboring regions, and μ denotes the output elasticity of (output density-related) agglomeration externalities spilling over from neighboring regions. Differences in labor efficiency (S_r) were controlled for by five to eight different levels of education of the population, depending on the country.

In Baptista (2003), finally, where regions were chosen to be UK counties, output density rather than average labor productivity was specified as a dependent variable, such that

$$\frac{Y_r}{A_r} = \left(Q\beta^{\beta} r^{-\beta}\right)^{\theta} \left(\frac{L_r}{A_r}\right)^{\alpha\theta}. \tag{6}$$

From the estimated elasticity of employment density (e.g., $\omega=\alpha\theta-1$ in eq. 5), the output elasticity of agglomeration externalities (λ) can be identified as

$$\hat{\lambda} = \frac{\gamma + (1-\beta)\hat{\omega}}{1+\hat{\omega}}, \tag{7}$$

provided the output elasticities of private-sector production (β and γ) are given (Ciccone 2002).

Based on data for U.S. counties in 1988, Ciccone and Hall (1996) estimated a density elasticity of average labor productivity ($\alpha\theta$ in eq. 4) of about six per cent. The supply of public services, externalities related to county size (total output), or externalities related to output density at the state level were not found to affect average labor productivity to a significant extent. Based on data for NUTS 3 regions in France, Germany, Italy, Spain and the UK in the late 1980s, Ciccone (2002) estimated a density elasticity of average labor productivity ($\alpha\theta$-1 in eq. 5) of about four per cent for intraregional agglomeration externalities. In addition, interregional spillovers of externalities were found to be significant: The elasticity of average labor productivity with respect to output density in neighboring NUTS 3 regions was estimated to be about three percent. Based on data for NUTS 3 regions in the UK in the late 1980s and early 1990s, finally, Baptista (2003) estimated a density elasticity of employment density ($\alpha\theta$ in eq. 6) of about seven per cent. Assuming the output elasticity of physical capital, β, to be 0.3, and that of land, 1-α-β, to be 0.015 (see Ciccone 2002), these estimates imply output elasticities of density (λ) of between 4.4 and six per cent.

The empirical approach developed in Ciccone and Hall (1996) has been widely recognized, not least so because of its theoretical generality and empirical simplicity. The model is consistent with several popular theoretical models, and draws upon a limited set of statistical data which are easy to obtain. Moreover, economic interpretation is straightforward. The results give an idea of the overall economic significance of external effects related to the concentration of economic activity in space.

The approach has a number of caveats, though.[4] First, the implied point estimate of the output elasticity of economic density ($\hat{\lambda}$ in eq. 7) is rather ambiguous because it depends crucially on what is assumed to be the output elasticity of land (γ). It is not possible to estimate γ from the Ciccone/Hall model because total area of a region is assumed to be both a public as well as private-sector input into production. Total area may appropriately proxy distance costs

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4 Extensive discussions of various issues related to the theoretical foundations and the empirical relevance of agglomeration externalities, including the pros and cons of the Ciccone/Hall approach by (1996), are given in Hanson (2001), and in several contributions to the forthcoming handbook of urban and regional economics (Henderson and Thisse 2004).

impeding agglomeration externalities.[5] But it is a rather poor proxy of the area available for commercial purposes, as, e.g., population is a poor proxy of the labor force. Across the 326 West German NUTS 3 regions, e.g., the share in total area actually used for commercial, non-agricultural purposes varies between 0.07 and 13 per cent, with an average of 1.7% in 1997. By comparison, the share in total population of the working-age population varies only between 63.4 and 72.6 per cent.

Second, the approach is very sensitive to biases induced by individual returns of various kinds which are observationally equivalent to, or at least correlated with, social returns to agglomeration. If, e.g., private returns to skills are not fully controlled for, or if white collar workers are more productive than blue collar workers with similar skills, the estimates will suffer from an omitted variable bias. As is well known, metropolitan areas usually are specialized in high-skilled and white collar occupations, while non-metropolitan areas are specialized in low-skilled and blue collar occupations (Bade and Schönert 1997; Duranton and Puga 2003; Bade et al. 2003). A similar bias may result from firm-specific increasing returns to scale of firms appropriated by the firms themselves. As is well known, big firms are over-represented in cities.

And third, the approach does not help answer the question of what kinds of externalities affect labor productivity, and to what extent. Regional output density is assumed to be a composite indicator of various different agglomeration externalities. On the one hand, this indicator may be too narrow. It may represent only a subset of the wide variety of positive and negative externalities (Duranton and Puga 2004). On the other hand, it may be too broad. It may represent specific externalities only to a limited extent.

2. Modifications

These potential shortcomings of the Ciccone/Hall approach suggest a number of extensions. The following discussion of the extensions proposed by the present paper will start from a region-specific production function similar to equation (2). For simplicity, however, labor efficiency (E_r) is assumed to be an argument of TFP. Empirical tests of the full extended model, as well as of each of the extensions will be presented in sections IV and V. The data set covers all 326 West German[6] NUTS 3 regions in 1997.

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5 At least for regular entities like circles or quadrates, the area (A) can be expressed as a function of the average distance between any two points (d). For a circle, $A=(45/128)^2\pi^3 d^2$; for a quadrate, $A\approx d^2/0.5214^2$.

6 East German NUTS 3 regions are excluded from the analysis because East Germany was still in the midst of economic transition in the mid-1990s, and because some of the data used in the present investigation are either not available for several East German Bundesländer, or are poorly reliable.

Modification 1: A distinction is made between area used for commercial, non-agricultural purposes (B_r),[7] entering private-sector non-agricultural production as an input, and total area of a region (A_r), determining social returns to economic density. Moreover, the constant returns to scale assumption is relaxed because erroneously assuming constant returns to scale in private-sector inputs might bias the estimated output elasticities of agglomeration externalities. Consequently, the term $A_r^{1-\alpha-\beta}$ in (2) is replaced by B_r^{γ}, with $\gamma \geq 0$ and $\alpha+\beta+\gamma \lesseqgtr 1$.

Modification 2: To capture a greater variety of private returns that may be correlated with agglomeration externalities, TFP (Q_r) is assumed a function of a number of (Hicks neutral) control variables, in addition to private returns to skills. First, highly innovative regions may be more productive because of private returns to R&D and innovation. Innovators may be able to appropriate monopoly rents from new knowledge, or new technologies they discovered. Although new technologies will diffuse across space sooner or later, and will eventually become available ubiquitously, there is evidence of new knowledge being localized (Audretsch and Feldman 2004; Bode 2004). Since innovative activities are highly concentrated in metropolitan areas, private returns to R&D and innovation may bias the parameter of the productivity effects of economic density upward, if not controlled for appropriately. In the present investigation, private returns to R&D and innovation are measured by the level of R&D activity of the regional economy (P_r), which is assumed to be a determinant of total factor productivity. As a proxy, the number of patent applications at the German Patent Office in the period 1992-1994 is used.[8]

Second, regional productivity differences may result from differences in occupational structures. For given skills of workers, labor productivity may be higher in white than in blue-collar activities. Since white-collar activities are highly concentrated in metropolitan areas (e.g., Duranton and Puga 2003; Bade et al. 2003), a higher labor productivity of these activities may bias the parameter of the productivity effects of economic density upward, if not controlled for appropriately. In the present investigation, the occupational composition of the regional workforce is introduced as a determinant of total factor productivity. As a proxy, the ratio of white and blue-collar workers in a region (WBC_r) is used.

Third, regional productivity differences may result from firm-specific increasing returns to scale which do not create agglomeration externalities at the regional level. In models of new economic geography, local input-output linkages are a necessary pre-condition for firm-

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7 Data on various land uses by NUTS 3 regions is available from land use statistics issued by the statistical offices of the Bundesländer. The statistics draw upon the local cadastral registers. Data for NUTS 3 regions in one Bundesland, Schleswig-Holstein, were lacking and had to be estimated, however. Appendix 2 describes the estimation procedure.

8 A more detailed description of data definitions and sources, as well as the correlation matrix is given in Appendix 2.

specific increasing returns to scale to create agglomeration externalities. If the increasing returns industries are operating at global rather than at the local markets, however, firm-specific returns to scale will not translate into agglomeration externalities at the regional level. In the present indicator, the distribution of firm sizes within a region is used as an indicator of the relevance of firm-specific increasing returns. Since bigger firms tend to be concentrated in metropolitan areas, firm-specific increasing returns of firms not serving the local markets may bias the parameter of the productivity effects of economic density upward, if not controlled for appropriately. Since statistical information on the spatial structures of the firms' sales markets are lacking, the firm-size structure of the regional economy as a whole is used as an indicator of the relevance of firm-specific increasing returns. As proxies, the employment shares of small firms (less than 20 employees; variable SF_r) and of big firms (more than 500 employees; BF_r) are used.

As proxies for private returns to skills (E_r), finally, the shares in the total workforce of high skilled workers (with a degree from a polytechnic or university; HSK_r), and of low skilled workers (with lower ("Hauptschule") or intermediate, "Realschule" school education; LSK_r) are used. In summary, thus, TFP is described by $Q_r = Q_r(Q, P_r, WBC_r, HSK_r, LSK_r, SF_r, BF_r)$, with Q denoting determinants of TFP which do not differ regionally, such as national institutional settings, national specialization patterns, or nationally ubiquitous technologies.

Modification 3: The present paper aims at capturing the output and productivity effects of a broader variety of agglomeration externalities than Ciccone and Hall (1996) by distinguishing three types of externalities, namely those related to economic density, to physical inputs into private-sector production, and to qualitative characteristics of the regional economies, such as human-capital intensities. This extension does, of course, not help identify the effects of specific externalities. It may, however, allow for capturing the agglomeration externalities at work more comprehensively, and for getting an idea about the relative importance of specific types of externalities.

First, the present paper follows Ciccone and Hall (1996) in specifying regional output density (output per square kilometer; Y_r/A_r) as a comprehensive measure of externalities related to economic density.

Second, the quantity of labor inputs (number of workers in the regional economy; L_r) is used to represent three types of externalities: social returns from input variety, social returns from a deeper division of labor among workers, and social returns from labor-market pooling. All three externalities can be shown to result in a positive relationship between output and the quantity of labor inputs in NEG-type models (see Ciccone and Hall 1996; Duranton and Puga 2004). Duranton and Puga (2004), e.g., show that labor-market pooling, or the gains from the division of a given number of tasks among workers result in a positive relationship between output and labor inputs of the kind $Y_r = f_1(L_r^{\alpha+\psi_L} \ldots)$, where α represents private-sector returns, and ψ_L is the composite elasticity of the three types of labor-related externalities.

Third, the quantity of land inputs in a region (commercial area; B_r) is used to represent diseconomies of congestion.[9] The functional form of the influence of congestion on output is assumed to be log-linear for simplicity, i.e., $Y_r = B_r^{\psi_B} \ldots$, with ψ_B<0 indicating diseconomies of congestion. As a consequence, the aggregate output elasticity of land, capturing private-sector and social returns, is $\gamma+\psi_B$.

Fourth, human-capital externalities are introduced by assuming labor efficiency (denoted by E_r in eq. 1) to depend positively on the skill composition of the regional workforce (HSK_r, LSK_r). Moretti (2004) provides an extensive discussion of theoretical and empirical issues of human-capital externalities.

Fifth, localized R&D spillovers are introduced by assuming total factor productivity to depend positively on the number of innovations developed in the respective regions in the recent past. This assumption is consistent with standard Dixit-Stiglitz endogenous growth models such as Rivera-Batiz (1988) where innovations are incorporated in varieties of an intermediate input. In a static equilibrium, total factor productivity of the sector producing the homogeneous consumption good depends positively on the number of innovations developed in the past. For simplicity, any piece of new knowledge developed in a specific region is assumed to produce region-specific externalities for only a limited time in the present paper. Afterwards, it is assumed to spill over instantaneously to all other regions. Having become ubiquitous, the knowledge ceases being a source of region-specific knowledge spillovers. Rather, it determines total factor productivity at the national level. Under these assumptions, localized knowledge spillovers result only from new knowledge developed in the recent past. In the present paper, the number of patent applications from the respective region in the period 1992–1994 (P_r) is used as a proxy for the intensity of localized knowledge spillovers.

Sixth, in NEG models the extent of social returns from the variety of intermediate inputs depends on the magnitude of the fixed costs the producers of intermediates incur. The higher the fixed costs, the lower will, ceteris paribus, be the (equilibrium) number of intermediates supplied and, thus, the respective social returns. In the present investigation, the firm-size structure (SF_r, BF_r) is used to control for regional differences in fixed costs. Since data on the firm-size composition of intermediate goods producers is not available, the firm-size composition of the entire regional economy is used as a proxy.

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9 Physical capital would clearly be another channel of externalities, as emphasized, e.g., in endogenous growth models with learning by doing (Romer 1986). However, since reliable data on regional capital stocks are lacking, no attempt is made to assess the relevance of physical capital for the creation or adoption of agglomeration externalities.

Finally, externalities related to labor-market pooling and human-capital spillovers (learning) are qualified by controlling for the occupational structure of the regional workforce (WBC_r). If these externalities are higher (lower) for white than for blue-collar occupations, this control variable will exhibit a positive (negative) influence on output, correcting the estimated average elasticity – the parameter ψ_L introduced above – upward (downward).

In summary, the production function (2) is extended by a function h_r,

$$h_r\left((Y_r / A_r), L_r, B_r, P_r, WBC_r, HSK_r, LSK_r, SF_r, BF_r\right),$$

describing the output effects of agglomeration externalities originating from within region r (indexed by r).

Obviously, the only argument in h_r which can be identified empirically is output density (Y_r/A_r). The output effects of the remaining externalities, related to input quantities and to qualitative characteristics of the regional economies (human-capital spillovers, localized R&D spillovers, magnitude of fixed costs, differences between occupations), cannot be identified because they are observationally equivalent to returns to private-sector production. This identification problem due to observational equivalence is a fundamental problem of investigations based on macro data. Nonetheless, it is important to realize that the estimated output effects of physical inputs and the determinants of TFP do not necessarily reflect private returns only but may result from social returns, and vice versa.

Modification 4: In contrast to *intra*regional effects of agglomeration externalities, *inter*-regional effects can be identified from macro data. They can be expected to not coincide with private returns because "senders" and "recipients" of these externalities differ. While the individual returns are appropriated in the region of origin, the related social returns may spill over to neighboring regions. Therefore, the output effects in region r of externalities originating from sources outside the region can be informative as to the comparative economic relevance of the different types of agglomeration externalities. As for externalities originating from within a region, three types of externalities are distinguished, namely those related to output density, to private-sector inputs, and to qualitative characteristics of neighboring regions. Formally, the production function (2) is extended by a function h_{Nr},

$$h_{Nr}\left((Y_{Nr} / A_{Nr}), L_{Nr}, B_{Nr}, P_{Nr}, WBC_{Nr}, HSK_{Nr}, LSK_{Nr}, SF_{Nr}, BF_{Nr}\right),$$

where Nr indexes origins outside region r.

As to the spatial scope of interregional spillovers of agglomeration externalities, the present paper focuses on externalities subject to spatial decay, i.e., on externalities the economic effects of which on recipients diminish with increasing distance to the origin.[10] The rationale behind this concept is a "spatial externality diffusion function" (Figure 1) describing a negative relationship between the distance between "sender" and "recipient" of a specific externality, and the economic effect on the recipient. The distance decay may result from physical transport costs, from traveling costs creating an impediment to frequent face-to-face contacts, or from other forms of spatial transaction costs.

As was noted earlier, the economic effects of externalities on agents within the region of origin cannot be identified unequivocally: Either the agents both produce and benefit from the externality, in which case the social returns resulting from the externality-producing activities cannot be distinguished from the respective private returns. Or producers and recipients are different but are mingled together in available statistical aggregates. The economic effects of externalities on agents outside the region of origin can be identified, by contrast, because the recipients there are definitely different – and can be distinguished statistically – from the producers. If the regions under consideration are not too big, and if the diffusion losses per unit of distance are not too high, agents in neighboring regions can be expected to be affected to some extent.

(Figure 1, Page 36)

The average size of the regions under consideration in the present paper is sufficiently small for expecting agglomeration externalities to extend beyond the regional borders. The average size of the 326 West German NUTS 3 regions is just 762 square kilometers. The radius of a circle of this area is less than 16 kilometers. In fact, there is some evidence of the economic influence of, in particular, larger cities extending far beyond their administrative borders. For example, the labor market in the city of Hamburg, which is a NUTS 3 region on its own, attracts roughly one third of the total workforce living in adjacent NUTS 3 regions. Moreover, many firms headquartering in the city of Hamburg have moved their production facilities to the suburbs in adjacent regions (see, e.g., Bode and Lammers 1994).

The empirical implementation of the externality diffusion function concept is rather difficult, of course. In practice, externalities may be generated at various places within regions, with quantities and qualities differing between the places. As a consequence, a specific location is subject to a multiplicity of overlaying externalities. They may or may not affect specific agents, and their economic effects may or may not accumulate. Moreover, regions may differ in size and the interior distribution of economic activities. As a consequence, the magnitudes

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10 The present investigation cannot address the effects of externalities that do not depend on physical or spatial proximity, such as network externalities (Johansson and Quigley 2004). Although network externalities appear to have much in common with (localized) agglomeration externalities, estimating their effects requires much more detailed information on the underlying network structures which is not available.

of economic effects becoming effective in their respective neighboring regions may differ as well. The present investigation can, at best, give a rather crude idea about the potential economic relevance of externalities. Nonetheless, on the backdrop of conventional wisdom holding that the effects of those externalities cannot be identified at all, it is at least a first step ahead.

Summing up, the structural form of the extended model, including the four modifications just discussed, is assumed to be

$$
\begin{aligned}
Y_r\left[= A_r Y_i\right] = {} & Q_r(Q, P_r, WBC_r, HSK_r, LSK_r, SF_r, BF_r)\ L_r^{\alpha} K_r^{\beta} B_r^{\gamma} \\
& h_r\left((Y_r / A_r), L_r, B_r, P_r, WBC_r, HSK_r, LSK_r, SF_r, BF_r\right) \\
& h_{Nr}\left((Y_{Nr} / A_{Nr}), L_{Nr}, B_{Nr}, P_{Nr}, WBC_{Nr}, HSK_{Nr}, LSK_{Nr}, SF_{Nr}, BF_{Nr}\right).
\end{aligned}
\tag{8}
$$

A number of simplifying assumptions concerning functional forms is necessary. First, the functional form of the private-sector productivity term, $Q_r(\cdot)$, should be general enough to capture the great variety of private returns as far as possible in order to prevent the effects of externalities from being biased. Given the rather limited scope of available statistical indicators, a linear, or log-linear functional form may be too restrictive. Therefore, a translog functional form is chosen for $Q_r(\cdot)$. More specifically, the six indicators for the determinants of TFP, namely the shares of low skilled and high skilled workers, patents, the white/blue collar workers ratio, and the shares of small and big firms, enter the model as (logged) levels, squares, and bilateral cross products. Hence, with the number of basic TFP determinants being $N = 6$, the total number of explanatory variables reflecting TFP is $0.5N(N+3) = 27$. Formally, $Q_r(\cdot)$ can be written as

$$
\ln Q_r(\cdot) = \ln Q + \sum_{i=1}^{N}\left[\delta_i \ln TFPDET_{ir} + \sum_{j=i}^{N}\delta_{ij}\left(\ln TFPDET_{ir} \ln TFPDET_{jr}\right)\right],
$$

where $TFPDET_r = \{P_r; WBC_r; HSK_r; LSK_r; SF_r; BF_r\}$.

Second, the functional forms of intraregional and interregional agglomeration externalities, $h_r(\cdot)$ and $h_{Nr}(\cdot)$, are assumed to be log-linear in the input quantities and translog (as above) in the quality-related arguments. Again, the translog function is intended to serve as a substitute for deficiencies resulting from limited statistical information, and as a means for capturing non-linear relationships between one or several characteristics and the underlying externalities.

Third, the spatial scope of externality spillovers is allowed to differ between the three groups of externality indicators. For simplicity, it is assumed to be the same within the three groups, however. The spatial scope is determined by the sets of neighbors to region r from with agglomeration externalities may spill over, denoted N_{rk} ($k = Y, C, L, B$), and the associated bilateral spatial weights, denoted $w_{r\tau k}$, determining the absolute or relative strength of the influences of each neighboring region τ ($\tau \in N_r$) onto region r. Absolute weights $w_{r\tau}$ indicate cumulative effects (e.g., size effects), relative weights which sum up to unity across all neighboring regions indicate average effects.

Fourth, the values of the indicators of externalities from neighboring regions are assumed to be geometric sums or averages across the respective values from each neighboring region. The employment-related externalities from all neighboring regions τ, e.g., are proxied by the quantity $\prod_{\tau \in Nr_L} L_\tau^{w_{Lr\tau}}$.

And fifth, physical capital (K_r) is replaced by its profit-maximizing quantity $(\beta/r)Y_r$, and the costs of capital and assumed to be same throughout the country, as in Ciccone and Hall (1996).

By introducing these assumptions into (8), concentrating output, Y, on the left-hand side, taking logs, and adding an error term, ε_r, the final empirical model to be estimated in the present paper can be derived as

$$
\begin{aligned}
\ln Y_r = \omega_0 &+ \sum_{i=1}^{N}\left[\omega_{1i}\ln TFPDET_{ir} + \sum_{j=i}^{N}\omega_{1ij}\left(\ln TFPDET_{ir}\ln TFPDET_{jr}\right)\right] \\
&+ \omega_2 \ln L_r + \omega_3 \ln B_r + \omega_4 \ln A_r \\
&+ \rho_Y \sum\nolimits_\tau w_{Yr\tau}\ln Y_\tau + \rho_A \sum\nolimits_\tau w_{Yr\tau}\ln A_\tau \\
&+ \sum_{i=1}^{N}\left[\phi_{Ci}\sum\nolimits_\tau w_{Cr\tau}\ln TFPDET_{i\tau}\right] + \sum_{i=1}^{N}\sum_{j=i}^{N}\left[\phi_{Cij}\sum\nolimits_\tau w_{Cr\tau}\left(\ln TFPDET_{ir}\ln TFPDET_{jr}\right)\right] \\
&+ \phi_L \sum\nolimits_\tau w_{Lr\tau}\ln(L_\tau) + \phi_B \sum\nolimits_\tau w_{Br\tau}\ln(B_\tau) + \varepsilon_r ,
\end{aligned}
\tag{9}
$$

where $\omega_0 = \beta\theta \ln\left(\frac{\beta}{r}\right) + \theta \ln Q$;

$\theta = 1/(1-\beta-\lambda)$

$\omega_{1i} = (\delta_i + \psi_{Ci})\theta$, $\omega_{1ij} = (\delta_{ij} + \psi_{Cij})\theta$, $i, j = 1, ..., 6$;

$\omega_2 = (\alpha + \psi_L)\theta$;

$\omega_3 = (\gamma + \psi_B)\theta$;

$\omega_4 = -\lambda\theta$;

$\rho_Y = -\rho_A = \lambda_N \theta$;

$\phi_{Ci} = \psi_{CiN}\theta$, $\phi_{Cij} = \psi_{CijN}\theta$, $i, j = 1, ..., 6$;

$\phi_L = \psi_{LN}\theta$;

$\phi_B = \psi_{BN}\theta$;

Y_r output in region r;
$TFPDET_r$ vector of N=6 proxies for TFP, controling for private (and social) returns to economic activity within region r;
L_r, B_r private-sector inputs of labor and area used for commercial non-agricultural purposes in r;
A_r total area of region r, reflecting externalities related to the density of economic activity in r;

Y_τ, A_τ	($\tau \in Nr_Y$) output and area in neighboring regions, reflecting externalities related to output density in neighboring regions;
$TFPDET_\tau$	($\tau \in Nr_C$) vector of N=6 proxies for qualitative characteristics in neighboring regions related to agglomeration externalities;
L_τ,	($\tau \in Nr_{YL}$) labor supply in neighboring regions;
B_τ	($\tau \in Nr_{YB}$) supply of commercial area in neighboring regions;
α,β,γ	elasticities of private-sector inputs in r;
δ_j	elasticities of TFP with respect to its determinants in r;
ψ_i	($i = C_j, L, B$) elasticities of externalities related to human capital etc., labor and commercial area in r;
ψ_{iN}	($i = C_j, L, B$) elasticities of similar externalities originating from neighboring regions;
λ	output elasticity of externalities related to output density in r;
λ_N	output elasticity of externalities related to output density in neighboring regions;
$w_{r\tau k}$	($k = Y, C, L, B$) bilateral spatial weights;
r	rental rate of capital;
ω, ρ, ϕ	regression parameters.

λ, λ_N, the ψ_i and the ψ_{iN} may be bigger or smaller than zero, depending on whether the respective externalities are positive or negative. ω_4<0 will indicate positive externalities of economic density, ω_4>0 negative. Equation (9) makes particularly clear that the parameters ω_{1j} through ω_3 will reflect both private and social returns. The output elasticities of labor (α) and commercial area (γ) as well as the elasticities of TFP with respect to the control variables (δ_j) cannot be identified without knowing the magnitude of the intraregional externalities working through these inputs (ψ_L, ψ_B, ψ_{Cj}).

The error term, ε_r, will capture, first, unobserved regional output variations resulting, i.a., from specific local policies and institutions, natural conditions, or regional differences in the rental rate of capital, resulting, e.g., from specific regional policy measures adopted by national or state governments. Second, it will capture unobserved random shocks hurting or benefiting single regions by chance. These unobserved output variations and shocks are assumed to be independent and normally distributed. In addition, the error term will capture unexplained regional interdependencies resulting, e.g., from a systematic interregional shock transmission, or from spillovers of externalities working through channels other than those specified in the model. In contrast to the unobserved variations, these systematic regional interdependencies can be identified by statistical tests for spatial dependence, and controlled for by additional explanatory variables, or by correcting for spatial autocorrelation (Anselin 1988).

The reasons for (i) choosing output rather than average labor productivity (Ciccone and Hall 1996; Ciccone 2002) or output density (Baptista (2003) as the dependent variable in (9), for (ii) choosing absolute labor rather than employment density as an explanatory variable, and for (iii) splitting up output density in neighboring regions into two variables (Y_N and A_N) will be discussed in the next section dealing with estimation issues. None of these choices had a significant impact on the results.[11]

To identify the parameters of the theoretical model, only one output elasticity must be known, rather than two, as in Ciccone and Hall (1996). For given β, λ can be identified from the estimator of ω_4, $\hat{\omega}_4$, as

$$\hat{\lambda} = \hat{\omega}_4(1-\beta)/(\hat{\omega}_4 - 1) \tag{10}$$

The other parameters of the theoretical model are functions of $\hat{\omega}_4$ and their own regression parameters, e.g., $(\hat{\alpha} + \hat{\psi}_L) = \hat{\omega}_2(1-\beta)/(1-\hat{\omega}_4)$.

III. Estimation issues

Before the regression results will be presented in section IV, a number of methodological issues is worth being mentioned, namely (1) potential problems resulting from endogeneity, (2) the repercussions of appropriate regression techniques on the choice of the dependent variable, (3) the choice of the appropriate spatial regime and the definition of spatial weights, (4) identification of the individual productivity effects of the determinants of TFP and the spillovers of externalities related to qualitative characteristics in neighboring regions, and (5) additional restrictions suggested by statistical tests.

Endogeneity

The issue of endogeneity of crucial explanatory variables has been discussed extensively in the literature. If explanatory variables are correlated with the error term, the respective parameter estimates will be biased and inefficient. In the present model, the crucial explanatory variable is total area of a region (ln$A$) which determines the output elasticity of density-related agglomeration externalities. Area can be expected to be exogenous because neither temporary output shocks nor historical output levels appear to have had a notable impact on the size of regions. There is, indeed, some indication of the last local governmental reforms in West Germany, dating back to the early 1970, having taken into consideration the degree of agglomeration and the economic strength of cities to a certain extent. Bigger cities, for example, were usually assigned city-Kreise, while smaller cities were merged with their neighboring hinterlands. However, the actual assignment rules differed a lot between Bundesländer: While Bavaria established a comparatively large number of city-Kreise, including small cities of less than 40,000 inhabitants back then, other Bundesländer established only few city-

[11] See Appendix 1 for a comparison of the regression results obtained for different definitions of the dependent variable.

Kreise. Moreover, in economic terms some cities (e.g. Munich) expanded far beyond their administrative boundaries since the early 1970s, while others (e.g., some cities in the Ruhr area) experienced a long-lasting depression. And third, there is actually no indication of a significant statistical correlation between total area and regional output in the sample under consideration (see Table A2 in Appendix 2). Therefore, the present paper follows Ciccone (2002) in assuming the geographical size of regions an exogenous variable, and, consequently, the estimated parameter of total area an unbiased function of the output elasticity of density (λ).

By contrast, endogeneity can be expected to be relevant for the variables reflecting the inputs to private-sector production, namely labor and commercial area ($\ln L$ and $\ln B$) as well as for some of the determinants of TFP. To account for potential endogeneity biases, several instruments for employment and commercial area were tested, including population and population density in the mid-1970s, as well as several functions of the dependent and explanatory variables, as suggested by Lewbed (1997) for the case of stochastic regressors.[12] None of the instruments affected the parameter estimates to a notable extent, and Hausman tests were highly insignificant, indicating that the instruments were either unnecessary or inappropriate. Therefore, effective instrumentation is not possible.

Regression techniques

The second issue is the choice of the appropriate regression technique, and its repercussions on the definition of the dependent variable. In the presence of a spatially lagged endogenous variable (output or output density in neighboring regions), OLS will yield biased estimates even if the residuals are not autocorrelated. Unlike in time-series regressions, the dependence across space must be assumed to be mutual rather than unidirectional (Anselin 1988). This problem can be dealt with in (at least) two alternative ways. The first way, preferred by Ciccone (2002), is employing an instrument variable (IV) approach which will yield consistent estimates, provided appropriate instruments are available. The second way is employing the maximum likelihood (ML) approach outlined in Anselin (1988) which should be preferred if appropriate instruments are not available.

As was noted above, endogeneity of the central region-specific explanatory variable (area) is not a problem of the specification preferred in the present paper. Consequently, the focus can be directed towards effectively reducing the bias resulting from endogeneity of the spatial lag. From tests of various instruments for output in neighboring regions the conclusion can be

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[12] As outlined in detail in the Appendix, commercial area in the NUTS 3 regions in Schleswig-Holstein had to be estimated and, thus, is subject to estimation errors. Following Lewbed (1997), the product of, e.g., regional employment and output, both mean-adjusted, and the products of employment and other explanatory variables, again mean-adjusted, were tested as instruments.

drawn that appropriate instruments are not available. Hausman tests indicate that the available instruments are at best useless. Consequently, the ML approach is preferred over the IV approach.

The cross-section ML approach is subject to the restriction that the spatially reduced form of the dependent variable exists, however. In matrix notation, the reduced form reads $(\mathbf{I}\text{-}\rho\mathbf{W})\boldsymbol{y}$. $\mathbf{I}$ denotes an (RxR) identity matrix (R: number of observations in the sample), ρ the parameter of the spatially lagged dependent variable to be estimated, $\mathbf{W}$ an (RxR) spatial weights matrix, and y the (Rx1) vector of observations for the dependent variable. Apparently, the reduced form exists only if the dependent variable of the structural model is the same as the spatial lag. Taking into consideration that, according to the theoretical model, the spatial lag is output density (Y/A), and that appropriate instruments are lacking, the dependent variable must be either output density (Y/A), or absolute output (Y) in the present investigation. Labor productivity (Y/L), by contrast, is not feasible. For the present purpose, total output is preferred because it is more general in that it allows for both assuming spillovers to depend on output density, or on total output in, and the sizes of neighboring regions.

Spatial regimes and spatial weights

The third issue is determining the appropriate spatial regime, including the spatial weights. First of all, it is important to make sure that the regression results obtained from the spatially lagged variables in (9) can, indeed, be interpreted as economically meaningful spillovers of agglomeration externalities. Note that (9) is very similar to a spatial error model, i.e., a model where spatial dependence is solely due to noise, caused, e.g., by interregional spillovers of idiosyncratic shocks, economically inappropriate regional boundaries, or omitted variables that are correlated across space. If all spatial weights in (9) were the same, it could, in matrix notation, be written as

$$y = \mathrm{X}\omega + \rho \mathrm{W}y + \mathrm{WX}\phi + \varepsilon\,.$$

The corresponding spatial error model, which is a region-specific model $y = \mathrm{X}\omega + u$ with the errors u following a spatial autoregressive process of the form $u = \mu \mathrm{W}u + \varepsilon$, can be written as

$$\begin{aligned} y &= \mathrm{X}\omega + \left(I - \mu W\right)^{-1}\varepsilon \\ &= \mathrm{X}\omega + \mu\mathrm{W}y - \mu\mathrm{WX}\omega + \varepsilon \\ &= \mathrm{X}\omega + \mu\mathrm{W}y + \mathrm{WX}\phi + \varepsilon. \end{aligned} \tag{11}$$

In spite of their formal similarity, the economic implications of the two specifications differ a lot (Anselin and Rey 1991). While (9) reflects a substantive spatial process, the spatial error model reflects just some nuisance spatial correlation that has little to do with economics.

To discriminate statistically between the two specifications, it is necessary to tests the so-called common factor hypothesis, based on an estimation of the spatial error model. The test of the common factor hypothesis is essentially a likelihood-ratio test of the restriction $\phi=-\mu\omega$ in (10) (Anselin 1988). In the present context, tests for various different spatial weights matrices, which are not reported here, clearly reject the common-factor hypothesis. Consequently, the parameters estimated from the spatially lagged variables in (10) can, in fact, be assumed to reflect the effects of interregional spillovers of agglomeration externalities, rather than just noise.

As to the definition of the spatial weights in (9), a number of simplifying assumptions are imposed to reduce complexity. The spatial weights are to determine the sets of neighboring regions N_{rk} ($k = Y, C, L, B$) from which agglomeration externalities may originate, and the associated weights, $w_{kr\tau}$, assigned to each of these regions. First, all spatially lagged variables reflecting externalities related to qualitative characteristics of neighboring regions ($C_{j\tau}$) are assigned the same weights, namely row-standardized binary first-order contiguity weights. I.e., the $w_{Cr\tau}$ in (9) are assumed to be equal to $1/R_r$ for NUTS 3 regions sharing a common border with r, and 0 else; R_r denotes the number of r's direct neighbors. Consequently, the parameters ϕ_{Cj} in (9) will reflect output elasticities with respect to the (unweighted) averages of the human capital and technology intensities as well as the occupational and firm size structures in directly neighboring regions.

Second, for simplicity the weights for employment and commercial area in neighboring regions are restricted to be the same. Of various different spatial regimes, inverse exponential distances with a distance decay of 0.02 turn out to yield the highest likelihood.[13] I.e., $w_{Lr\tau}$ and $w_{Br\tau}$ in (9) is assumed to be equal to $\exp(-0.02d_{r\tau})$, where bilateral interregional distances, $d_{r\tau}$, are approximated by traveling time by car between the economic centers of the respective NUTS 3 regions r and τ in minutes. A cut-off of 120 minutes is introduced, assuming interdependencies between NUTS 3 regions with a distance of more than 120 minutes to be negligible or random. In general, inverse exponential distance weights are comparable to iceberg transport costs, with marginal losses decreasing in distance. A distance decay of –0.02 implies that about 45% of an impulse are melting away over a distance of 30 minutes; less than 10% survive a distance of two hours which is the cut-off in the present case. The spatial weights

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13 The spatial regimes tested include binary first, and first and second-order contiguity, the k-nearest neighbors concept, inverse distances, and inverse exponential distances. See Bode (2004) for a more detailed description of the spatial weights. It should be noted that the strategy adopted here of testing different spatial weights is somewhat dubious methodologically because the impact of the spatial regime on the covariance matrix is ignored. In ML regressions the spatial weights must be assumed strictly exogenous. On the other hand, reliable a priori information about the appropriate weights is not available. Just picking a single arbitrary weighting scheme from the basket of economically plausible weights generally entails a high risk of failure. Performing some sort of a grid search across a limited set of plausible spatial weights therefore was assumed as a compromise.

are not row-standardized. Consequently, the parameters ϕ_L and ϕ_B in (9) reflect elasticities with respect to the distance-weighted sum (or potential) of workers, or commercial areas in NUTS 3 regions whose economic centers are accessible within two hours.

Employing the same grid search as for inputs related externalities, the appropriate weights for spatially lagged output and area $w_{Yr\tau}$, finally, turn out to be unstandardized binary first-order contiguity weights. Standardization is, nonetheless, achieved implicitly through dividing output by area. Therefore, the output density-related spillovers of agglomeration externalities reported below depend on the unweighted average of the output densities in directly neighboring NUTS 3 regions.

Identification issues

The individual elasticities of output with respect to the six basic determinants of TFP, and to externalities related to qualitative characteristics in neighboring regions cannot be determined from the point estimates for the respective 27 parameters for two reasons: First, the assumed functional forms are highly non-linear, and second, the individual variables are far from being uncorrelated. In fact, the shares of low and high-skilled workers, for example, are correlated fairly highly with each other as well as with the occupational and the firm-size compositions (see Table A2 in Appendix 2). As a consequence, determining the individual output elasticities of any of these explanatory variables requires taking into consideration the correlation with the other explanatory variables.

In the present paper, the individual output elasticities are determined from the partial derivatives of the regression model (9) with respect to each of the six variables representing TFP, resp. externality spillovers, while accounting for the correlation with the other TFP, resp. externality spillover determinants. To account for the non-linearities, the partial derivatives are calculated at the first, second and third quartiles, Q(x), x = 1, 2, 3, of the respective variables. Formally, the elasticities $\hat{\pi}_k(x) = {d \ln Y}\big/{d \ln TFPDET_k}\,|_{Q(x)}$ for the the k-th determinant of TFP at the value of its x-th quartile are calculated from

$$\ln Y_r = \ldots + \sum_{i=1}^{N}\left[\hat{\omega}_{1i} \ln \widehat{TFPDET}_{ir} + \sum_{j=i}^{N}\hat{\omega}_{1ij}\left(\ln \widehat{TFPDET}_{ir} \ln \widehat{TFPDET}_{jr}\right)\right] \tag{12}$$

where $\ln \widehat{TFPDET}_{ir}$, e.g., is a predicted value of $\ln TFPDET_{ir}$, obtained from an auxiliary regressions of $\ln TFPDET_i$ on $\ln TFPDET_k$,

$$\ln \widehat{TFPDET}_{ir} = \hat{a}_{ik} + \hat{b}_{ik} \ln TFPDE_{kr},$$

to capture the correlation between the two variables, and the parameters $\hat{\omega}$ are those obtained from estimating (9). The estimated elasticity is obtained as

$$\hat{\pi}_k(x) = \sum_{i=1}^{N} \hat{\omega}_{1i} \hat{b}_{ik} + \sum_{i=1}^{N} \sum_{j=i}^{N} \hat{\omega}_{1ij} \left(\hat{a}_{ik} \hat{b}_{jk} + \hat{a}_{jk} \hat{b}_{ik} + 2 \hat{b}_{ik} \hat{b}_{jk} \ln TFPDET_k \,|_{Q(x)} \right), \tag{13}$$

$k = 1, \ldots, 6$; $x = 1, 2, 3$. Of course, $a_{kk} = 0$ and $b_{kk} = 1$. The partial derivative of output with respect to the share of high-skilled workers at the value of the first quartile, e.g., reflect the change in output in a region with comparatively little supply of high-skilled workers induced by a marginal change in the share of high-skilled workers, and corresponding marginal changes in the other TFP determinants (e.g., share of low-skilled workers), which are typically observed in the sample data set under consideration.

Although it would, in principle, be possible to estimate standard deviations of the elasticities $\hat{\pi}_k(x)$, this exercise is left to future investigations.

Statistical tests

The fifth empirical issue, finally, is related to modifications and corrections of the empirical model (9) suggested by statistical tests. For the residuals to pass normality and homoscedasticity tests, five outlying observations have to be neutralized by dummies. These modifications do, however, not affect the parameters estimates of interest to a significant extent. Moreover, parameter stability tests suggest estimating the parameter of employment density ($\ln L$) separately for regions with below and above average labor productivity. Since there is no indication for a corresponding instability of the parameters of commercial and total area ($\ln B$ and $\ln A$), the instability is assumed to result neither from differences in the region-specific output effects of economic density (λ) nor from differences in the output elasticity of physical capital (β).There may be several explanations for the observed parameter instability: Private or social returns to labor (α, ψ_L) or to human capital may be higher in high productivity regions.[14] Or the costs of living may rise more than proportional to productivity. Since the quantitative effects of the non-linearity are rather limited, as will be shown below, a closer inspection of the reasons for this non-linearity will be left to future research.

[14] Rosenthal and Strange (2003), e.g., found that (especially young) full-time professionals worked longer hours in regions with a higher local density of other workers of the same occupation. Higher returns to agglomerated labor may thus be partly due to the selection of hard workers into cities, to higher competition or rivalry between them, and/or to better opportunities for careers.

IV. Results for the full extended model

Table 1 reports the results of the ML regression for (9) for a cross section of 326 West German NUTS 3 regions 1997. The first, upper panel reports the estimates for the regression parameters in (9). All parameter estimates and standard deviations are in per cent for expositional convenience.[15] The second panel reports the implied estimates for the elasticities of the underlying theoretical model, calculated according to (10) assuming the output elasticity of physical capital (β) to be 30%, as usual in the literature (see, e.g., Ciccone 2002). The standard deviations of the implied parameters, estimated employing the delta method (Bishop et al. 1975: 492 ff.), should be interpreted with caution. Their estimation involves a first-order Taylor approximation, assuming the variance of the elasticity of physical capital (β) to be zero. The last panel in Table 1 reports the log-likelihood, the Akaike information criterion (AIC), and the pseudo R^2. The pseudo R^2 indicates that model (9) explains more than 99% of the total variation in value added across the West German NUTS 3 regions.[16] The overwhelming majority of the explanatory power accrues to the inputs of the private production function (labor, commercial area).

(Table 1, Page 37)

The estimation results for the implied output elasticities in the second panel of Table 1 indicate that the results obtained in earlier investigations may, in fact, have been subject to considerable omitted variable biases: First, the output elasticity of economic density (λ) is estimated to be very low (0.44%) and not significantly different from zero at conventional significance levels.[17] Earlier investigations reported highly significant point estimates of between 4.4% (Ciccone 2002) and 6% (Baptista). As will be shown in Section V and Appendix 3, the difference is, to a good deal, due to a more extensive and more effective control for private returns in the present paper. Second, the output elasticity of economic

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[15] The implied elasticities of the individual region-specific TFP indicators and the corresponding interregional externality spillovers indicators are listed in Table 2. Table 1 reports only the likelihood ratio (LR) test statistics from tests of joint significance of the respective 27 explanatory variables (not in per cent). More details about additional test statistics (i.a. normality, homoscedasticity, parameter stability, spatial dependence) are available from the author upon request.

[16] Since the Jacobian of the likelihood function is very low (-1E-4), the pseudo R^2 can be interpreted in a similar way as the (unadjusted) R^2 of an OLS regression.

[17] The results presented in Table 1 are robust against variations of the dependent variable and the regression method (as discussed in section III) as well as against the inclusion of NUTS 2 region dummies. Table A1 in appendix 1 presents the results of ML estimations for different dependent variables, namely average labor productivity, preferred by Ciccone and Hall (1996) and Ciccone (2002), and output density, preferred by Baptista (1996). Column (5) of Table A4 (appendix 3) presents the results of a two-stage least squares instrument variable estimation for a model similar to (9), but with average labor productivity as the dependent variable, as preferred by Ciccone (2002). And column (4) of Table A3 (appendix 3) reports the results of an ML estimation of (9) including NUTS 2 region dummies.

density in neighboring regions (λ_N) is estimated to be very low and statistically insignificant as well. The two point estimates for λ_N, referring to output ($\hat{\lambda}_{N(Y)}$=–0.03%) and the geographical size of neighboring NUTS 3 regions ($\hat{\lambda}_{N(A)}$=0.19%), indicate that output density in neighboring regions may even have a weak negative effect on regional output and productivity.[18] Ciccone (2002) reported a highly significant point estimate of about 3%. As will be shown below, the difference is also due to a more extensive and more effective control for private returns. Third, the output elasticity of commercial area is estimated to be 2.83%. In Ciccone (2002) it was assumed to be 1.5%. Estimating rather that pre-determining the elasticity of land affects the estimate for the elasticity of economic density (λ) only to a limited extent, however (see Appendix 3). And fourth, the 27 control variables for private (and social) returns are jointly highly significant. Earlier investigations included only the skills indicators.[19]

The implied estimates for the elasticities of individual TFP determinants, derived by the procedure described in the preceding section (section III; equation 13), show plausible signs (Table 2, upper panel). They suggest regional productivity to depend positively on the patent intensity, the share of white-collar workers (as opposed to blue-collar workers), the skills intensity and the relevance of big firms within a region. Although the point estimates should not be taken with caution because they do not allow for distinguishing private from social returns and may be subject to endogeneity biases, it is interesting to note that the elasticities tend to vary across the sample quartiles of the respective basic TFP determinants. In contrast to the elasticity of output with respect to regional patent intensity which varies little with the number of patent applications, the productivity effects of the skills, the firm-size and the occupational structures are fairly sensitive to levels. For example, output and productivity appear to be affected much stronger by a marginal change in the skills composition of the workforce in regions where skills are abundant (high share of high-skilled, low share of low-skilled workers) than in regions with a comparatively low (average) skill level.[20] Essentially the same result obtains for the firm-size composition: Output and productivity appear to be affected much stronger by a marginal change in the firm-size composition in regions dominated by big firms than in regions dominated by small firms. The reasons for these

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[18] The parameters are, however, not statistically significant – neither individually nor jointly. The hypothesis of $\lambda_{NY} = \lambda_{NA} = 0$ is not rejected by an LR test at conventional significance levels (prob=0.15).

[19] Likelihood ratio test indicate that each of the two skills indicators (shares of high and low-skilled workers) as well as each of the four other basic TFP determinants (innovativeness, white/blue collar workers ratio, shares of small and big firms) contribute significantly to explaining regional output and productivity. The implied parameter estimates of the TFP determinants will be discussed below.

[20] The magnitude of the point estimates can be expected to depend on the particular definition of high and low-skilled workers. In the present investigation, the definition of low-skilled workers is fairly broad, which probably contributes to the point estimate of the elasticity for low-skilled workers being much higher than that for high-skilled workers.

differences in the estimated elasticities cannot be determined in the present paper. In particular, the question of to what extent the differences are due to differences in the relevance of externalities must be left to future research.

(Table 2, Page 38)

Returning to Table 1, the point estimates for the output elasticity of labor ($\alpha+\psi_L$) are 66.43% for low and 66.98% for high productivity regions. In total, the three elasticities of labor, capital and land sum up to 99.26% for low and 99.81% for high productivity regions which is not significantly different from 100%. Since it is unknown to what extent the point estimates reflect social returns to labor and land, or are subject to endogeneity biases, a test of the hypothesis of constant returns to scale in private-sector production may be misleading, however.

Interregional spillovers of externalities related to labor and land inputs in neighboring regions are found to be statistically significant but of only limited absolute magnitude: A doubling of employment in close spatial proximity apparently raises regional output and productivity by ($\hat{\psi}_{LN}=$) 0.06%, while a doubling of the supply of commercial sites depresses regional output and productivity by ($\hat{\psi}_{BN}=-$) 0.37%. Since interregional externality spillovers reflect just the tails of spatial externality diffusion functions discussed in section II, they cannot be expected to be of high absolute magnitude. What is important here is that the estimation results suggest that input-related externalities are relevant determinants of regional output and productivity in principle. If this was true, and if the concept of spatial externality diffusion functions was a useful one, externalities related to labor and land inputs could be assumed to significantly affect output and productivity within regions as well.[21]

Interregional spillovers of externalities related to skills, technology, occupational and firm size structures in neighboring regions, finally, are estimated to jointly have a significant impact on output as well (LR=89.9; prob<0.001; Table 1). The individual implied elasticities estimated for the six basic characteristics (Table 2, lower panel) are broadly consistent with the respective estimates for the TFP determinants within regions (upper panel): Externalities related to the patent and skill intensities as well as the occupational structure (white/blue-collar ratio) in neighboring regions are also estimated to affect output and productivity positively, an the elasticities also appear to increase with patent intensity, skill level and white-collar activities. The point estimates of the interregional externality spillovers are generally lower than the respective point estimates of the intraregional TFP elasticities. Again, what is most important here is that the results suggest that the respective externalities

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[21] Consequently, the private output elasticity of labor (α) would be somewhat lower, and the private output elasticity of commercial area (γ) somewhat higher than indicated by the estimates of the combined private and social elasticities, $\alpha+\psi_L$ and $\gamma+\psi_B$.

are relevant determinants of regional output and productivity in principle, and that they may be taken as an indication of the respective externalities to be relevant within regions as well.

In a nutshell, the results obtained for the extended Ciccone/Hall model in the present paper do not support earlier findings of externalities related to economic density significantly enhancing regional productivity. Rather, externalities related to input factor quantities and qualities are found to significantly affect regional productivity.

V. Tests of individual modifications

Where do the differences in the results between the present investigation and earlier investigations come from? This section summarizes the empirical results for gradual extensions of the basic Ciccone/Hall model by the modifications suggested in section II. Modification 3, of course, introducing a broader variety of region-specific externalities, is not testable separately because the effects of the externalities cannot be identified. Since, among the earlier investigations, Ciccone (2002) is related to the present one most closely, it is used as the main reference for comparisons. The tests of the single modifications suggest the following conclusions:[22]

1. About half of the difference between Ciccone (2002) an this paper in the estimated effects of output density (parameter λ) is due to differences in the data: Roughly 1½ to 2 percentage points are due to different data for the indicators of labor efficiency, or human capital. While Ciccone (2002) used 1987 census data reflecting education of the working-age population at their places of residence, this paper uses data from social security insurance statistics in 1997 reflecting education of employees at their workplaces. Due to extensive commuting flows between the NUTS 3 regions, human-capital indicators referring to the place of residence do probably reflect the skills composition of workers at their workplace (where the value added is created) not too precisely. Roughly another half of a percentage point is due to different definition of value added. While Ciccone (2002) used 1986 value added at market prices which includes excise duties, the present paper uses 1997 value added at production costs which is net of excise duties. There is some evidence of industries subject to high excise duties (fuel, tobacco and liquors in particular) being over-represented in metropolitan areas.[23]

2. The second half of the difference between Ciccone (2002) an this paper in the estimated effects of output density (λ) is due to insufficient control for private returns to factor inputs and the determinants of TFP (modification 2). λ turns statistically insignificant and negligible

[22] A detailed description of the test designs and results are given in Appendix 3.

[23] An example is the concentration oil and tobacco industries in Hamburg.

in magnitude once private (and social) returns other than those to skills are controlled for. To what extent the control variables actually reflect social rather than private returns, must be left to future research (see modification 3). What the results do indicate, however, is that even if the additional control variables reflected externalities in the first line, there would be no reason to assume these externalities to be closely related to economic density per se. They are, apparently, conductive to output and productivity in rural areas, as they are in metropolitan areas.

Apart from skills, particular high explanatory power emanates from firm size. Having been largely neglected in most empirical investigations so far, private and/or social returns to scale apparently affect regional output and productivity to a significant extent.

3. As density externalities within regions, density externalities spilling over from neighboring regions turn insignificant once additional control variables are introduced. Quite interestingly, controlling for the "recipient" region's characteristics turn out to be sufficient. That is, output density within a region, and output density in neighboring regions appear to play similar roles: They pick up variation in productivity that is not explained by region-specific factors. Whether or not this variation actually is resulting from externalities is merely a matter of chance.

4. In contrast to economic density, physical inputs employed in neighboring regions, and qualitative characteristics of the neighboring regions seem to reflect economic forces. Their output and productivity effects remain significant even in the presence of the full set of controls for region-specific characteristics.

5. Dummies for higher layers of administrative units are poor substitutes for economic interdependencies between neighboring regions. The NUTS 2-region dummies turn jointly insignificant once the characteristics of neighboring regions are controlled for.

VI. Conclusions and prospects for future research

The present paper addresses a number of conceptual weaknesses of a model proposed by Ciccone and Hall (1996) for estimating the productivity effects of urbanization economies or, more specifically, of agglomeration externalities related to economic density. The model is extended in several respects. The extensions allow for controlling more thoroughly for private returns which may be correlated with agglomeration externalities, for estimating, rather than predetermining, crucial parameters of the model, and for gaining insights into the relevance of localization economies or, more specifically, of externalities related to the supply of labor and commercial sites, to innovation, to human capital intensity, and to firm size. The extensions are tested using data for 326 West-German NUTS 3 regions.

In contradiction to the results reported in earlier studies, the paper finds localization rather than urbanization externalities to significantly affect regional productivities. While the positive productivity effects of economic density disappear when private returns are controlled for more appropriately, productivity effects of externalities related to the supply of labor and of commercial sites, to human capital intensity, and to firm size are found to be robust and of plausible signs. The latter externalities may be linked in some respects to economic density. They may be relevant in metropolitan areas. But, apparently, economic density is neither a precondition for these externalities to be effective, nor is it an appropriate indicator for these externalities.

According to conventional wisdom, the economic effects of localization externalities, like those related to the supply of labor and of commercial sites, to innovativeness, human capital intensity and firm size, cannot be uncovered from aggregate data because they are observationally equivalent to private returns. The paper argues that this is true only for the effects of externalities within spatial units. In fact, spillovers of externalities between spatial units can be identified because equivalent private returns can be expected to be appropriated within the regions of origin only. One condition is that the externalities that are subject to distance decay, which most types of agglomeration externalities are assumed to be. Although the productivity effects of externalities spilling over from neighboring regions are estimated to be highly significant statistically, their absolute effects are estimated to be rather limited. But this is hardly surprising given that the spillovers from neighboring regions reflect just the lower tails of the respective "spatial externality diffusion functions". Unfortunately, the results are informative only with respect to the principle relevance of the externalities. Their aggregate economic consequences can, by contrast, not be assessed because the shapes of the spatial externality diffusion functions are unknown.

The paper illustrates that exploiting the spatial dimension offers some potential for gaining insights into the economic relevance of agglomeration externalities from aggregate, macroeconomic data. Pursuing further this line of research, a number of issues appear to be worth being investigated more thoroughly in future investigations. First, distance decay functions for specific indicators of agglomeration externalities in neighboring regions can be estimated endogenously by non-linear least squares techniques. If the spatial units within the sample are sufficiently small, the functions may reveal more detailed information about the shape of "spatial externality diffusion functions". Second, exploiting information on the spatial distribution of economic activity *within* regions (e.g. at the city level), and employing the distribution index suggested in Ciccone and Hall (1996), will improve the reliability of the density indicator. Moreover, combining the information on city sizes and characteristics with proxies for economic distances between the cities may allow for specifying testable models of intraregional externality diffusion functions. Third, controlling for returns to physical capital will not only reduce omitted variable biases further (Moomaw 1983), but will also allow for assessing the relevance of learning-by-investing externalities. And finally, disaggregating by industries and/or occupations is clearly an issue because industries differ significantly in the extent to which they produce, or are subject to agglomeration externalities (e.g., Henderson 2003).

Appendix 1: Additional Tables

(Table A1, Page 39)

Appendix 2: Data

The following data were used in the regression analysis:[24]

Output (Y_r): Three years' (1996–1998) average of annual nominal gross value added (at production costs) in manufacturing and service industries, excluding the primary sector but including the public sector. Value added data of the public sector is not available. Data source: Statistisches Landesamt Baden-Württemberg (February 2002 release).

Employment (L_r): Three years' (1996–1998) average of number of persons employed in manufacturing and services industries, excluding the primary sector but including the public sector. Data source: Statistisches Landesamt Baden-Württemberg (February 2002 release).

Area (A_r): Total area in square kilometers. Source: Statistisches Bundesamt.

Commercial Area (B_r): area actually used by commercial firms (Gewerbe, Industrie) on December 31, 1996, Sorce: German federal statistical office (Statistisches Bundesamt, („Flächenerhebung nach Art der tatsächlichen Nutzung am 31.12.1996“). Data for 15 NUTS 3 regions in Schleswig-Holstein which are not available were estimated by the following procedure: For each of the 15 NUTS 3 regions, a minimum of four reference NUTS 3 regions from other parts of West Germany was chosen that most closely resembled the respective NUTS 3 region in Schleswig-Holstein with respect to their land use patterns. The reference regions were identified by means of a cluster analysis, based on seven indicators which were available for all regions (including those in Schleswig-Holstein):

– share in total area of parcels occupied by buildings of any kind, including unimproved areas serving purposes which were subordinated to the main purposes of the buildings) ("Gebäude- und Freiflächen"),
– share in total area of agricultural area,
– ratio of parcels occupied by buildings (see above) to the number of persons employed;
– ratio of area of parcels occupied by buildings (see above) to total population;
– ratio of area of parcels occupied by buildings (see above) to gross value added;
– share of persons employed in total population;
– local property tax rate.

50 regional clusters were created by means of the cluster analysis, eight of which included the 15 Schleswig-Holstein NUTS 3 regions.

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[24] See Table A2 for the correlation matrix.

Within each of the eight clusters (c), the Schleswig-Holstein members were assigned the average share of commercial area in total area occupied by buildings, as observed from the non Schleswig-Holstein members. Formally,

$$B_i(c) = BB_i(c)\left[{}^{1}\!/_{N(c)} \sum\nolimits_{j \in c, j \neq i} \frac{B_j(c)}{BB_j(c)} \right].$$

B denotes commercial area, BB total area of parcels occupied by buildings, i indexes Schleswig-Holstein NUTS 3 regions, c clusters, and j non Schleswig-Holstein NUTS 3 regions, and $N(c)$ the number of non-Schleswig-Holstein members of cluster c.

Innovativeness (P_r) average of 1992-1994 numbers of patent applications by commercial firms situated in Germany at the German and European Patent Offices, regionalized according to the place of residence of the innovator. Source: Greif 1998.

Occupational structure (WBC_r): 1999 ratio of blue (Fertigungsberufe) and white collar workers (Dienstleistungsberufe) covered by the public social insurance system. The German public social security insurance system covers about 70% to 80% of the entire workforce. It does not cover self-employed and specific part-time workers. Source: Bundesamt für Bauwesen und Raumordnung (2001).

Share of high-skilled workers (HSK_r): share in all workers covered by the public social insurance system of workers with a degree from a polytechnic (Fachhochschule) or an university. Source: Landesarbeitsamt Schleswig-Holstein.

Share of low-skilled workers (LSK_r): share in all workers covered by the public social insurance system of workers with lower or intermediate school education ("Hauptschule", "Realschule"). Source: Landesarbeitsamt Schleswig-Holstein.

Share of small firms (SF_r): employment share of firms with less than 20 employees in 1987, according to the 1987 general census. Source: ZEW.

Share of big firms (BF_r): employment share of firms with 500 or more employees in 1987, according to the 1987 general census. Source: ZEW.

Interregional distances ($d_{r\tau}$): traveling time by car between the economic centers of NUTS 3 regions r and τ in minutes in 1999. Source: IRPUD Dortmund (see Schürmann and Talaat 2000a; 2000b).

(Table A2, Page 40)

Appendix 3: Setup and results of tests of individual modifications

This appendix investigates the sources of the differences in estimation results between the present paper and earlier investigations based on the Ciccone/Hall approach. As a reference for the earlier investigations Ciccone (2002) is chosen because it provides estimates for the same German NUTS 3 regions a decade earlier (1986). As a point of departure, a basic model is estimated which is as close as possible to the model estimated by Ciccone (2002). Remaining differences to the Ciccone-model will be discussed with respect to their effects on the estimates. The basic model will be extended stepwise by the modifications introduced in section II in order to investigate the sensitivity of results to the individual modifications. The last step will arrive at the model estimated in Section IV. It should be noted that the point estimates and inferential statistics (standard deviations, probability values) presented in this appendix may be poorly reliable because of omitted variable biases, parameter instabilities, spatial dependence, heteroscedasticity, and/or non-normality.

The model resembling the one estimated in Ciccone (2002) most closely is, in the notation used in section II,

$$\begin{aligned}\ln\frac{Y_r}{L_r} &= \text{constant} + \omega_{11}\ln HSK_r + \omega_{12}\ln LSK_r + \omega_2\ln\frac{L_r}{A_r} \\ &\quad + \rho\sum\nolimits_\tau w_{r\tau}\ln\frac{Y_\tau}{A_\tau} + \text{NUTS 2 dummies} + \varepsilon_r,\end{aligned} \tag{A1}$$

where $\omega_2 = (\alpha\theta - 1)$, $\rho = \lambda_N\theta$ and $\theta = 1/(1\text{-}\beta\text{-}\lambda)$. As in Ciccone (2002), the constant returns to scale assumption (α+β+γ=1) applies, and dummies for NUTS 2 regions control for regional differences in the rental rates of capital and land. The output elasticity of economic density (λ) is calculated from the parameter of employment density assuming $\beta = 30\%$, γ=1.5% and, consequently, $\alpha = 68.5\%$. (A1) is estimated by a two-stage least squares instrument variable approach, using total area, A_r and A_τ, as instruments for employment density in region r (L_r/A_r) and output density in neighboring regions (Y_τ/A_τ).

Conceptually, (A1) differs from the model estimated in Ciccone only in the relative weights of neighboring regions in the spatially lagged variable. In (A1) all neighbors of a specific region are assigned the same weights, while in Ciccone neighbors are weighted by their geographical size. While there is, a priori, no reason for preferring one over the other scheme on theoretical grounds, the definition doesn't make a big difference. The two specifications produce almost the same R^2 and likelihood values, and the inferential statistics are not affected to a notable extent. Nonetheless, the specification in (A1) produces an implied elasticity of output density in neighboring regions (λ_N) which is about 0.3 percentage points lower.

With respect to the empirical implementation, there are a few important differences to Ciccone (2002), however. First, the present paper uses data on value added at production costs in 1997, while Ciccone (2002) used value added at market prices (including excise duties) in 1986. According to test regressions for 1992, a year for which data for both definitions of value added are available, the estimated effects of economic density (λ) tend to be about half a percentage point higher with market prices than with production costs. The reason is presumably a concentration of industries subject to high excise duties (on, e.g., fuel, tobacco, liquor) in densely populated areas.[25]

Second, the present paper controls for returns to human capital by the two indicators introduced in section II, namely the shares of low and high skilled workers in 1997 (HSK_r and LSK_r). The data source is public social security insurance statistics which covers employees at their workplace. In Ciccone (2002), by contrast, "the fraction of the population with one of six to eight education levels" (Ciccone 2002: 220) in 1987 is used. The data source is the 1987 general census which covers the entire working-age population at the place of residence. Test regressions indicate that the estimated effects of economic density (λ) tend to be about 1.5 to 2 percentage points higher with the 1987 census-based indicators. In light of extensive commuting flows between German NUTS 3 regions, human-capital indicators referring to the place of residence do presumably reflect the skills composition of workers at their workplace (where the value added is created) not too precisely.

And third, the data-set specific modifications discussed in section III are retained here: Five outlying regions are neutralized by dummies, and the elasticity of employment density is estimated separately for low and high-productivity regions. The implied estimator of the output elasticity of density (λ)is calculated from the estimated parameter of employment density in regions with above-average productivity.

The estimation results for the basic model (A1) are given in column (1) of Table A3. The output elasticity of economic density is estimated to be positive and statistically highly significant. The point estimate for λ is 1.51% which is about 3 percentage points lower than the 4.4% reported in Ciccone (2002). As noted earlier, most of this difference (2 – 2.5 percentage points) is due to differences in the data sets (value added, human-capital indicators). The point estimate for the elasticity of economic density in neighboring regions (λ_N) is 2.62% which is about 0.7 percentage points lower than the 3.3% reported in Ciccone (2002). Most of this difference (about half a percentage point) is due to the different weighting scheme for neighboring regions. In summary, thus, it may be concluded that the fundamental relationship between economic density and regional productivity apparently did not change much from the late 1980s to the late 1990s.

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[25] One example is the concentration oil and tobacco industries in Hamburg.

(Table A3, Page 41)

Test of modification 1

Modification 1 in section II (i) relaxes the constant returns to scale assumption and (ii) introduces a distinction between total area (A_r) – as a determinant of the externality – and commercial area (B_r) – as an input into private-sector production. Two changes will be analyzed separately. First, relaxing the constant returns to scale assumption gives

$$\begin{aligned} \ln Y_r = {} & \text{constant} + \omega_{11} \ln HSK_r + \omega_{12} \ln LSK_r + \omega_2 \ln L_r + \omega_4 \ln A_r \\ & + \rho_Y \sum\nolimits_\tau w_{r\tau} \ln Y_\tau + \rho_A \sum\nolimits_\tau w_{r\tau} \ln A_\tau + \text{NUTS 2 dummies} + \varepsilon_r ; \end{aligned} \tag{A2}$$

$\omega_2 = \alpha\theta$, $\omega_4 = (\gamma - \lambda)\theta$, and $\rho_Y = -\rho_A = \lambda_N \theta$.

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Figure 1 — Spatial externality diffusion function

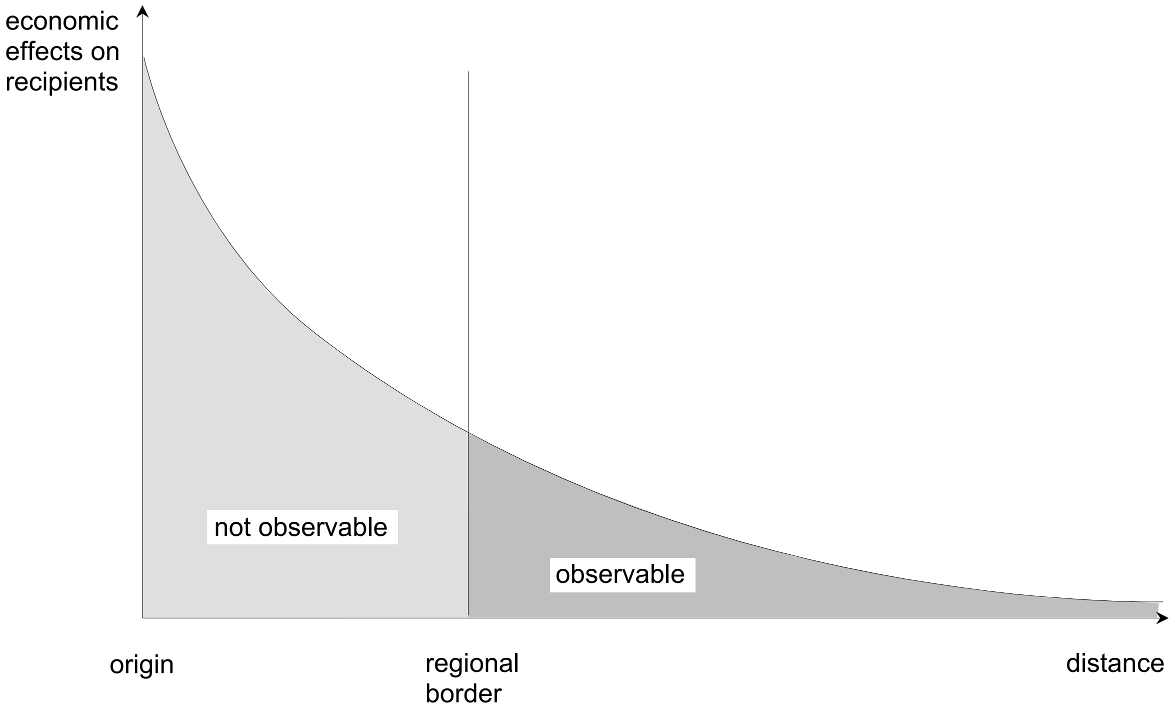

Table 1 — Agglomeration effects in West German regions 1997[a]

explanatory variable[b]	parameter	estimate (*100)	std. dev. (*100)	prob
labor ($\ln L_r$) low productivity regions	ω_{21}	95.50	1.39	0.00
labor ($\ln L_r$) high productivity regions	ω_{22}	96.29	1.40	0.00
commercial area ($\ln B_r$)	ω_3	4.07	1.14	0.00
total area ($\ln A_r$)	ω_4	–0.64	0.80	0.43
output neighbors ($\Sigma w_{\mathrm{N01}r\tau} \ln Y_\tau$)	ρ_Y	–0.03	0.07	0.50
total area neighbors ($\Sigma w_{\mathrm{N01}r\tau} \ln A_\tau$)	ρ_A	0.19	0.18	0.29
employment neighbors ($\Sigma e^{-0.02 d r\tau} \ln L_\tau$)	ϕ_L	0.08	0.02	0.00
commercial area neighbors ($\Sigma e^{-0.02 d r\tau} \ln B_\tau$)	ϕ_B	–0.53	0.16	0.00
27 control variables	ω_{1j}	210.65[c]		0.00
27 spatially lagged control variables	ϕ_{Cj}	89.91[c]		0.00
implied output elasticities[d]				
output density	λ	0.44	0.55	0.42
labor low productivity regions	$\alpha+\psi_L$	66.43	1.05	0.00
labor high productivity regions	$\alpha+\psi_L$	66.98	1.05	0.00
commercial area	$\gamma+\psi_B$	2.83	0.78	0.00
output neighbors	$\lambda_{N(Y)}$	–0.02	0.04	0.50
total area neighbors	$\lambda_{N(A)}$	0.13	0.13	0.28
employment neighbors	ψ_{LN}	0.06	0.02	0.00
commercial area neighbors	ψ_{BN}	–0.37	0.11	0.00
no of region-specific dummies			5	
no of observations			326	
lnL			539.34	
AIC			–942.7	
pseudo R^2			0.996	

[a] Results of a cross-section maximum likelihood regression for 326 West German NUTS 3 regions 1997; dependent variable: log regional gross value added ($\ln Y_r$).

[b] w_{N01}: first-order binary contiguity weights; s: row-standardized; $e^{-0.02 dr\tau}$: inverse exponential distances, distance decay: 0.02; for detail, see the text.

[c] LR test of joint significance (not in %).

[d] Calculated assuming the elasticity of physical capital β=30%. Standard deviations estimated using the delta method.

Table 2 — Agglomeration effects in West German regions 1997 – estimates of elasticities of output with respect to individual TFP determinants and indicators for externality spillovers from neighboring regions[a]

explanatory variable	estimated elasticities $\hat{\pi}_k(x)$ for quartile (%)		
	1	2	3
TFP determinants region *r*			
patents (ln*P*)	2.38	2.57	2.76
White/blue collar ratio (ln*WBC*)	0.40	2.62	4.75
share high-skilled workers (ln*HSK*)	3.54	5.83	9.43
share low-skilled workers (ln*LSK*)	-59.96	-24.47	-1.39
share small firms (ln*SF*)	-55.98	-40.27	-23.52
share big firms (ln*BF*)	10.11	25.66	44.06
externality spillovers from neighbor. regions			
patents (ln*P*)	0.69	1.31	1.80
White/blue collar ratio (ln*WBC*)	-2.97	0.77	5.00
share high-skilled workers (ln*HSK*)	0.56	1.78	2.97
share high-skilled workers (ln*LSK*)	-21.97	4.54	23.35
share small firms (ln*SF*)	-1.85	2.46	7.81
share big firms (ln*BF*)	-15.52	-5.06	7.70

[a] The estimation method is described in detail in Section III.

Table A1 — Agglomeration effects in West German regions 1997 – comparison of regressions with output ($\ln Y$), output density ($\ln(Y/A)$), or labor productivity ($\ln(Y/L)$) as the dependent variable[a]

variable (spatial weights[b])	parameter	$\ln Y$	$\ln(Y/A)$	$\ln(Y/L)$
labor ($\ln L_r$) low productivity regions	ω_{21}	95.50	95.18	–4.76
		(1.39)	(1.37)	(1.37)
labor ($\ln L_r$) high productivity regions	ω_{22}	96.29	95.98	–3.96
		(1.40)	(1.37)	(1.37)
commercial area ($\ln B_r$)	ω_3	4.07	4.12	4.09
		(1.14)	(1.14)	(1.14)
total area ($\ln A_r$)	ω_4	–0.64	–100.26	–0.34
		(0.80)	(0.74)	(0.75)
output neighbors ($\Sigma w_{N01r\tau} \ln Y_\tau$)	ρ_Y	–0.03	0.02	0.04
		(0.05)	(0.02)	(0.02)
total area neighbors ($\Sigma w_{N01r\tau} \ln A_\tau$)	ρ_A	0.19	—	—
		(0.18)		
employment neighbors ($\Sigma e^{-0.02 d r \tau} \ln L_\tau$)	ϕ_L	0.08	0.08	0.08
		(0.02)	(0.02)	(0.02)
commercial area neighbors ($\Sigma e^{-0.02 d r \tau} \ln B_\tau$)	ϕ_B	–0.53	–0.52	–0.52
		(0.16)	(0.16)	(0.16)
implied output elasticities[c]				
output density	λ	0.44	0.18	0.24
		(0.55)	(0.51)	(0.52)
labor low productivity regions	$\alpha+\psi_L$	66.43	66.45	66.45
		(1.05)	(1.05)	(1.05)
labor high productivity regions	$\alpha+\psi_L$	66.98	67.01	67.00
		(1.05)	(1.06)	(1.06)
commercial area	$\gamma+\psi_B$	2.83	2.87	2.86
		(0.78)	(0.79)	(0.79)
spatially lagged dependent variable	λ_N	–0.02	0.02	0.03
		(0.04)	(0.01)	(0.02)
total area neighbors	$\lambda_{N(A)}$	0.13	—	—
		(0.13)		
employment neighbors	ψ_{LN}	0.06	0.06	0.06
		(0.02)	(0.02)	(0.02)
commercial area neighbors	ψ_{BN}	–0.37	–0.36	–0.36
		(0.11)	(0.11)	(0.11)
number of observations		326	326	326
lnL		539.34	538.61	538.84
AIC		–942.7	–943.2	–943.7
pseudo R^2		0.996	0.999	0.843

[a] Results of cross-section maximum likelihood regressions for 326 West German NUTS 3 regions 1997; approximate standard deviations in parentheses.

[b] N01: First-order binary contiguity weights; S: row-standardized; $e^{-0.02 d r \tau}$: Inverse exponential distances, distance decay: 0.02; for detail, see the text.

[c] Calculated assuming the elasticity of physical capital β=30%. Standard deviations estimated using the delta method.

Table A2 — Correlation matrix for the basic variables used in the regression[a]

	ln*Y*	ln*L*	ln*B*	ln*A*	ln*P*	ln*WBC*	ln*HSK*	ln*LSK*	ln*SF*	ln*BF*
ln*Y*	1.00	0.99 (0.00)	0.74 (0.00)	-0.02 (0.65)	0.70 (0.00)	-0.42 (0.00)	0.69 (0.00)	-0.63 (0.00)	-0.52 (0.00)	0.44 (0.00)
ln*L*		1.00	0.76 (0.00)	0.01 (0.86)	0.67 (0.00)	-0.41 (0.00)	0.64 (0.00)	-0.60 (0.00)	-0.49 (0.00)	0.41 (0.00)
ln*B*			1.00	0.37 (0.00)	0.48 (0.00)	0.03 (0.60)	0.24 (0.00)	-0.24 (0.00)	-0.27 (0.00)	0.29 (0.00)
ln*A*				1.00	0.06 (0.25)	0.43 (0.00)	-0.47 (0.00)	0.33 (0.00)	0.57 (0.00)	-0.41 (0.00)
ln*P*					1.00	-0.18 (0.00)	0.56 (0.00)	-0.43 (0.00)	-0.32 (0.00)	0.35 (0.00)
ln*WBC*						1.00	-0.69 (0.00)	0.81 (0.00)	0.11 (0.04)	-0.02 (0.71)
ln*HSK*							1.00	-0.81 (0.00)	-0.57 (0.00)	0.50 (0.00)
ln*LSK*								1.00	0.27 (0.00)	-0.28 (0.00)
ln*SF*									1.00	-0.83 (0.00)
ln*BF*										1.00

[a] Pearson correlation coefficients; prob-values in parentheses.

Table A3 — Agglomeration effects in West German regions 1997 – tests of individual modifications[a]

	(1) 2SLS IV[b] basic model	(2) ML basic model, no CRS	(3) ML modifica-tion 1	(4) ML modifica-tions 2+3	(5) ML modifica-tion 4
parameter estimates					
labor ($\ln L_r$) low-productivity regions	-2.08	100.88	93.22	92.68	94.83
	(0.70)	(1.08)	(1.52)	(1.67)	(1.64)
labor ($\ln L_r$) high-productivity regions	0.02	101.72	94.03	93.46	95.62
	(0.69)	(1.07)	(1.51)	(1.67)	(1.65)
commercial area ($\ln B_r$)	—	—	8.97	5.81	4.88
			(1.32)	(1.28)	(1.26)
total area ($\ln A_r$)	—	-1.58	-2.64	-0.07	-0.59
		(0.72)	(0.69)	(0.82)	(0.82)
output density / output neighbors ($\ln Y_\tau$)[c]	3.83	0.03	-0.04	-0.01	-0.03
	(1.16)	(0.06)	(0.05)	(0.05)	(0.06)
area neighbors ($\ln A_\tau$)	—	0.10	0.28	0.14	0.17
		(0.21)	(0.20)	(0.18)	(0.21)
employment neighbors ($\Sigma e^{-0.02 d r\tau} \ln L_\tau$)	—	—	—	—	0.10
					(0.04)
comm. area neighbors ($\Sigma e^{-0.02 d r\tau} \ln B_\tau$)	—	—	—	—	-0.58
					(0.24)
implied output elasticities[d]					
output density (λ)	1.51	2.56	1.80	0.05	0.41
	(0.51)	(0.48)	(0.46)	(0.57)	(0.57)
labor (α) low-productivity regions	[68.50]	71.01	63.57	64.42	65.99
	—	(0.76)	(1.10)	(1.16)	(1.20)
labor (α) high-productivity regions	[68.50]	71.60	64.13	64.96	65.54
	—	(0.76)	(1.10)	(1.16)	(1.21)
commercial area (γ)	[1.50]	[1.50]	6.12	4.04	3.39
	—	—	(0.89)	(0.88)	(0.87)
output density / output neighbors (λ_{NY})[c]	2.62	0.02	-0.03	-0.01	-0.02
	(1.04)	(0.04)	(0.04)	(0.03)	(0.04)
total area neighbors (λ_{NA})	—	-0.06	0.19	0.10	0.11
		(0.14)	(0.13)	(0.12)	(0.14)
employment neighbors (ψ_{LN})	—	—	—	—	0.07
					(0.02)
commercial area neighbors (ψ_{BN})	—	—	—	—	-0.41
					(0.17)
no of TFP determinants	2	2	2	27	27
no of spatially lagged quality indicators	0	0	0	0	27
no of NUTS 2 dummies	29	29	29	29	29
no of region-specific dummies	5	5	5	5	5
LR test of modification	—	—	43.26	137.61	92.47
prob (DOF)			0.00 (1)	0.00(25)	0.00 (29)
LR test of joint significance of λ_{NY} and λ_{NA}	—	22.86	10.98	6.14	3.01
prob		0.00	0.00	0.05	0.22
lnL	392.29	425.11	446.74	515.54	561.78
AIC	-704.58	-766.22	-807.48	-895.08	-929.56
adj. R^2	0.611	0.992	0.993	0.996	0.997

[a] Regressions for 326 West German NUTS 3 regions 1997; dependent variable: logged output. Approximate standard deviations in parentheses. Parameters and standard deviations are in per cent.
[b] Dependent variable: logged average labor productivity; instruments: log total area of the region, resp. neighboring regions. Approximate White-robust standard deviations in parentheses.
[c] Column (1): output density; columns (2)-(5): total output.
[d] Standard deviations estimated using the delta method assuming β=30%.. Parameters in square parentheses are assumed given.